(12) UK Patent Application (19) GB (11) 2 152 657 A

(43) Application published 7 Aug 1985

(21) Application No 8400181

(22) Date of filing 5 Jan 1984

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(51) INT CL[4]
G01N 21/45 H04R 23/00

(52) Domestic classification
G1A A3 A7 C4 C8 CE G17 G18 G7 P16 P3 P6 PH R7 S4 T15 T5
U1S 1947 G1A

(56) Documents cited
None

(58) Field of search
G1A

(54) Interferometers

(57) An interferometer comprising in combination light generating means 1–5 for producing coherent light, light splitting means 8 arranged to route light from said light generating means over two different paths one of which includes a fibre optic sensor 9 and the other which comprises a by-pass reference path of predetermined length, light combining means 10 arranged to receive the light after passage through said sensor and said by-pass path to provide an output of combined light, said two paths being located in such close proximity relative to one another as to be subjected substantially to the same ambient conditions, in which light derived from said light generating means is divided into periods of two different frequencies W1, W2, before the light is routed through said fibre optic sensor and the by-pass path and is combined by said light combining means, or light of a single frequency emerging from the combining means is combined with light of a different frequency derived from said light generating means, before the light is fed to a heterodyning optical detector 11, in which the light passing through said fibre optic sensor will be phase modulated due to variations in the characteristics of the fibre optic sensor during operation of the interferometer and in which means is provided for preventing the generation of more than one time-division multiplex signal by said heterodyning optical detector, or at least preventing the arrival of more than one such time division-multiplex signal at the input of a phase or frequency modulation receiver 14 coupled to the optical detector.

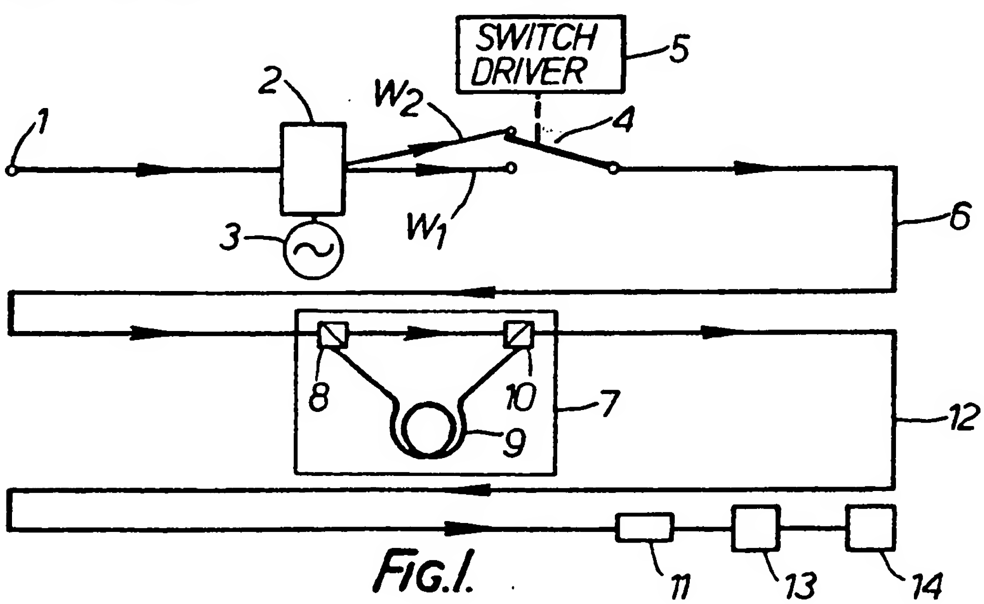

FIG.1.

GB 2 152 657 A

The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.
The claims were filed later than the filing date within the period prescribed by Rule 25(1) of the Patents Rules 1982.

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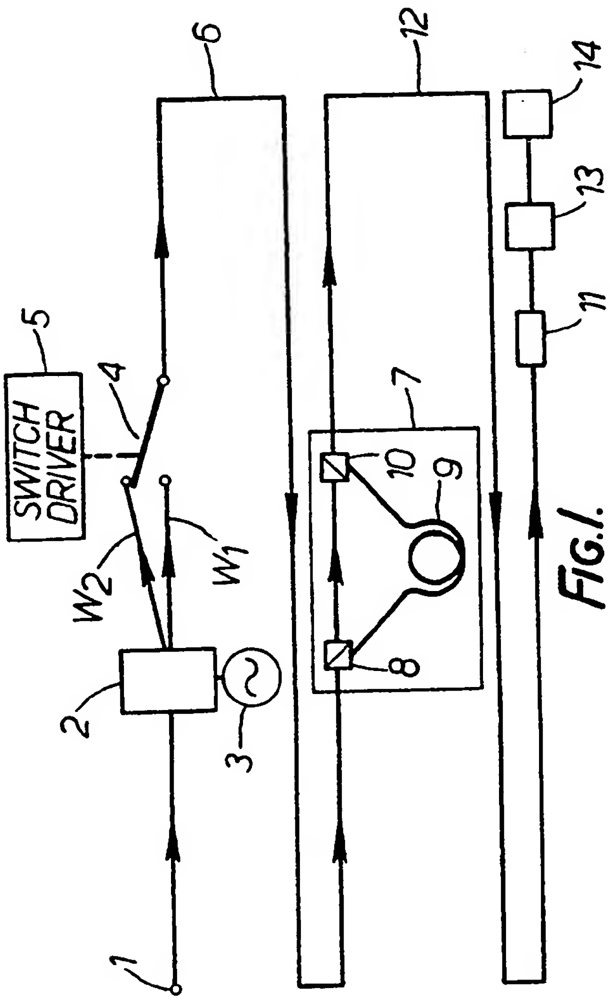

FIG.1.

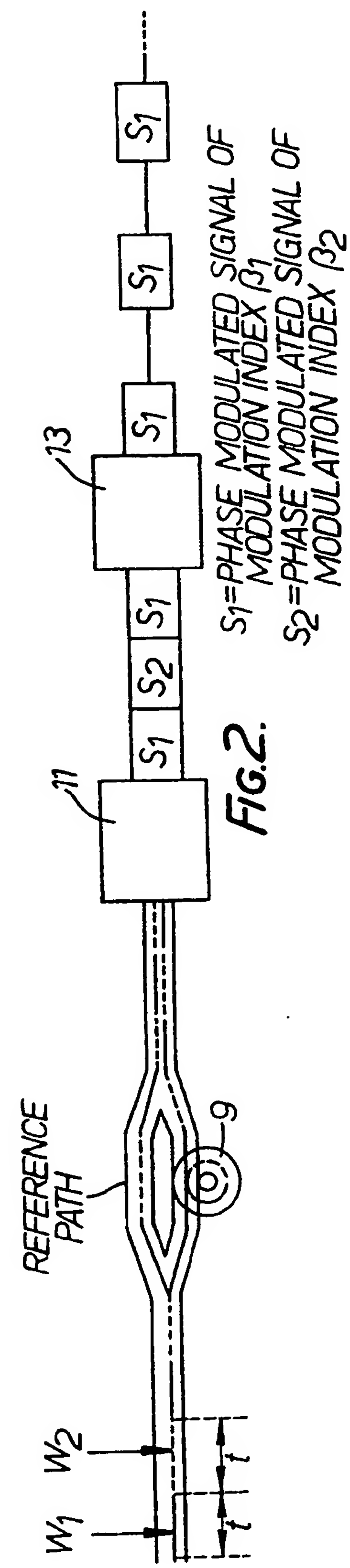

FIG.2.

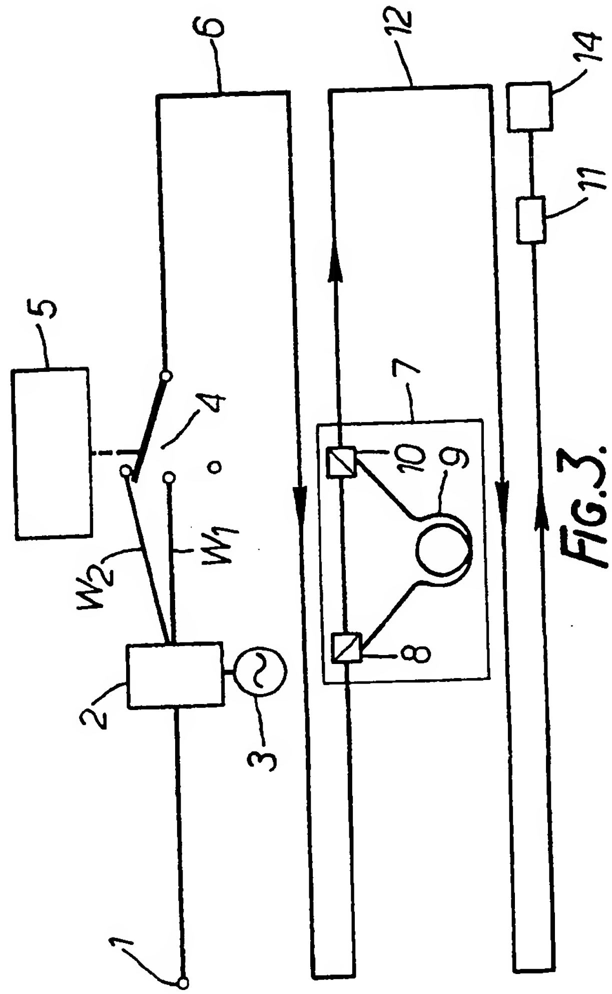
1
2
3
W2
W1
4
5
6
7
8
9
10
12
11
14

FIG.3.

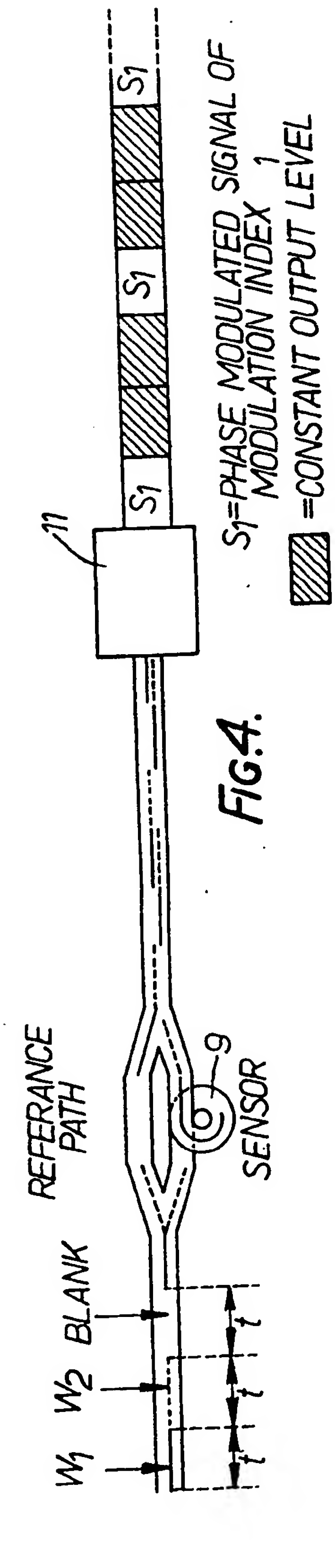
W1
W2
BLANK
t
t
t
REFERANCE PATH
9
SENSOR
11
S1
S1
S1
S1=PHASE MODULATED SIGNAL OF MODULATION INDEX 1
=CONSTANT OUTPUT LEVEL

FIG.4.

SPECIFICATION

Improvements relating to int rferometers

This invention relates to interferometers and more particularly to interferometers in which a fibre optic sensor can be located remotely from a generator of coherent light and an optical detector for the sensed signals.

In our co-pending Patent Application No. 8034178 there is described an interferometer in which a beam of coherent light derived from generator means (e.g. laser) and alternating between one frequency (W1) and another frequency (W2) for like periods (t) is routed simultaneously over two paths. One of these two paths includes a fibre optic sensor which responds mechanically and optically to the impingement thereon of acoustic signals whereas the other path constitutes a reference path which by-passes the fibre optic sensor. The length of the sensor path relative to the reference or by-pass path is such that the light passing through the sensor is delayed by a period (t) with respect to the light through the reference path. The light from the two paths is combined and fed to an optical detector. The light from the reference or by-pass path alternates in frequency between the frequencies (W1) and (W2) and has a period (t). The light from the path containing the fibre optic sensor also alternates between frequencies (W1) and (W2) but during operation of the interferometer for detecting acoustic signals impinging on the fibre optic sensor the light in the fibre optic sensor path experiences phase modulations due to such impingement of acoustic signals on the sensor. Furthermore, the time delay imposed by the fibre optic sensor causes the light from the appertaining path to differ in frequency from the light from the reference or by-pass path by the values (W1−W2) and (W2−W1) alternately.

The light from the fibre optic sensor and reference paths in falling on the optical detector previously referred to causes the latter to produce an output comprising two signals time—division—multiplexed together one of which results from light at frequency (W1) in the reference or by-pass path being heterodyned with light at frequency (W2) in the fibre optic sensor path and the other of which results from light at frequency (W2) in the reference or by-pass path being heterodyned with light at frequency (W1) in the fibre optic sensor path.

The output signals from the optical detector are phase-modulated carrier signals which have modulation indices of opposite signs and slightly different magnitudes. This poses difficulties when demodulating these signals for the detection of phase modulation due to the impingement of acoustic signals on the fibre optic sensor since the direct use of a phase-modulation receiver or frequency-modulation receiver will result in a low amplitude output, distortion and fading. This is because the receiver demodulates both of the time-division-multiplexed signals as a single signal.

According to the present invention there is provid d an int rferometer of the general form hereinbefore described but comprising means effective for preventing the generation of or at least the arrival of more than one time-division-multiplexed signal at the input of the pahse modulation or frequency modulation receiver of the interferometer.

According to one manner of carrying out the present invention, one of two time-division-multiplexed signals from the optical detector which receives the combined light from the respective reference and fibre optic paths is gated or electrically switched out of the path to the demodulator. This gating out procedure leaves an intermittent phase-modulated carrier only to be demodulated by the phase-modulation or frequency-modulation receiver which can accordingly provide a stable, undistorted output of sufficient amplitude.

According to another manner of carrying out the present invention, means are provided wherby the light beam which alternates between one frequency (W1) and another frequency (W2) for like time periods (t) is interrupted at appropriate intervals to produce an absence of light for a period (t) following successive alternations in frequency from (W1) to (W2).

With this arrangement the light from the fibre optic and reference paths of the interferometer are combined to produce heterodyning of the light at frequency (W2) from the fibre optic sensor path with light at frequency (W1) from the reference or by-pass path. The output from the optical detector accordingly comprises a single phase modulated signal which can be demodulated without the aforesaid difficulties arising by by means of a phase-modulation or frequency-modulation receiver.

By way of example the present invention will now be described with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of an interferometer constructed in accordance with the present invention;

Figure 2 is a diagram which indicates the passage of light through the interferometer of Fig. 1;

Figure 3 is a schematic diagram of a modified form of interferometer according to the inv ntion; and

Figure 4 is a diagram similar to that of Fig. 2 but showing the passage of light through the modified interferometer shown in Fig. 3.

Referring to Fig. 1 of the drawings, the interferometer depicted is of the same general construction as that described in our co-pending patent Application No 8034178 (2087545). The interferometer which is util-

ised as a hydrophone comprises a laser 1 constituting a source of coher nt light of fr - quency (W1) which is fed into a Bragg cell 2. In the present example the Bragg cell has applied to it from a signal generator 3 a modulating signal of frequency (WM) so that the output from the cell comprises signals of frequencies (W1) and (W1 + WM). An optical switch 4 then selects the frequency (W1) or (W1 + WM) (equals W2) from the output of the Bragg cell and the resultant signal alternates between these frequencies (W1) and (W2) at a predetermined rate by the operation of switch driver means 5. It will be appreciated that alternative arrangements for obtaining alternating frequency signals could be provided. In the present example, however, a time-division-multiplexed signal comprising shifted signals (W2) and unshifted signals (W1) each of period (t) is produced. This time-division-multiplexed signal is launched into a so-called downward optical fibre line 6 extending to a remotely located hydrophone head 7. This head includes a beam splitter 8 which divides the multiplexed beam into two and directs the divided beam over respective paths. One of these paths includes a coiled fibre optic sensor 9 whilst the other path constitutes a reference path which by-passes the fibre optic sensor 9. The two paths terminate at a combiner 10 which receives the light from the two paths the length of the reference path relative to the fibre optic sensor path being such that the combiner receives contemporaneously signals of the frequencies (W1) and (W2) and provides an output as shown in Fig 2 comprising superimposed signals of frequencies (W1) and (W2). Preferably, the signal delay introduced by the fibre optic sensor 9 is equal to the period (t) of each of the signals of frequency (W1) and (W2).

The combined signals from the combiner 10 of the hydrophone are fed to a photodetector 11 through an upward optical fibre line 12. The photodetector 11 has a square law characteristic which results in heterodyning between components of the combined signals.

The light passing through the sensor 9 is phase modulated by acoustic signals due to mechanical and acousto-optic effects when acoustic signals impinge on the coiled sensor 9. Accordingly, the output signals from the optical detector 11 will be phase-modulated carrier signals which have modulated indices of opposite signs and slightly different magnitudes.

In accordance with the invention the embodiment of interferometer presently being described includes gating means 13 which, as can be seen from Fig. 2, s rv s to remove one of th phase-modulated signals (S2). The other phase-modulated signal (S1) is fed to a phase-modulaion or frequency-modulation receiver 14 for the detection of phase modulation caused by the impingement of acoustic waves on the coiled fibre optic sensor 9.

It can b shown that the output from the gating means consist of the following components:—

(a) a d.c. component of magnitude $\frac{1}{2}k(A^2 + B^2)$;

(b) a square wave of frequency WC and amplitude $k(A^2 + B^2)$;

(c) a phase-modulated carrier at frequency WB having phase modulation:

$$\text{Phase} = -\phi 1 = -\frac{W1(1+\Delta 1)}{C}$$

This phase is composed of a slowly varying part, namely,

$$-W1\ \frac{1}{C}$$

(which varies because 1 changes with temperature, pressure etc) and a part reflecting the acoustic modulation, namely,

$$-W1\Delta\ \frac{1}{C}.$$

The gating increases the modulation by a factor

$$F = \frac{2W1}{WB}$$

In the above expressions.

A = amplitude of field from fibre optic beam.

B = amplitude of field from reference path beam

k = constant

(W1 =) (W2 =) two frequencies of light used.

1 = length of fibre optic sensor

Δ1 = extension of fibre sensor due to sound.

C = velocity of light in fibre

WB = W2 − W1

$$WC = \frac{2\Pi}{2t}$$

In a typical system using WB = 100 MHz and light of wavelength 633 wm the factor F is of the order of 10^7.

The carri r has an amplitude given by: amplitude = kAB. This is a constant so that there is no fading or amplitude modulation.

(d) a set of pairs of phase-modulated carriers at WB ± WC, WB ± 3WC, WB ± 5WC etc. These have phase modulation:

3

$$\text{phase} = \pm \frac{W1(1+\Delta 1)}{C}$$

and do not display fading or amplitude modulation.

Referring now to Figs. 3 and 4 of the drawings these show a modified embodiment of invention in which the light beam launched into the downward optical fibre line 6 comprises alternate signals of frequency (W1) and (W2) of period (t) as in the Fig. 1 embodiment, but the signal of frequency (W2) is followed by an interruption of duration (t) in the light beam. In order to achieve this signal pattern in the fibre 6 the optical switch 4 has three switching positions and be actuated by switch driver means 5 at time intervals(t).

As can be seen from Fig. 4 of the drawings, only the superimposed signals (W1) and (W2) will be heterodyned by the photo-detector 11 with the result that the output from the photodetector will comprise only one phase-modulated signal (S1) which is then fed to a phase-modulation or frequency-modulation receiver 14 for the detection of phase modulation produced by the acoustic energy impinging on the fibre optic sensor. By not generating one of the phase modulated signals in the photodetector 11 the modulation receiver will be able to produce an undistorted signal output of sufficient amplitude which is a measure of the phase modulation produced by the impingement of acoustic waves on the fibre optic sensor 9.

In the case of this modified embodiment it can be shown that the output from the photodetector 11 consists of the following components:

(a) a d.c. component of magnitude

$$\frac{2}{3}k$$

$(A^{\prime} + B^{\prime})$

(b) two rectangular waves of amplitude $kA^{\prime}$ and $kB^{\prime}$, respectively, and having mark-space ratio of 1:2, frequency WC and differing in phase by

$$\frac{2\Pi}{3}$$

radians.

(c) a phase-modulated carrier of frequency WB and amplitude

$$\frac{2}{3}k$$

AB whose phase is given by:

$$\text{phase} = -\phi 1$$

$$= -\frac{W1(1+\Delta 1)}{C}$$

There is no fading or amplitude modulation and the carrier has the same modulation index as the gated out signal referred to above in relation to Figs. 1 and 2.

(d) a set of pairs of phase-modulated carriers at frequencies of WB $\pm$ WC, WB $\pm$ 2WC, WB $\pm$ 4WC etc. These have the same phase-modulation index as in (c) above.

CLAIMS

1. An interferometer in combination light generating means for producing coherent light, light splitting means arranged to route light from said light generating means over two different paths one of which includes a fibre optic sensor and the other which comprises a by-pass reference path of predetermined length, light combining means arranged to receive the light after passage through said sensor and said by-pass path to provide an output of combined light, said two paths being located in such close proximity relative to one another as to be subjected substantially to the same ambient conditions, in which light derived from said light generating means is divided into periods of two different frequencies before the light is routed through said fibre optic sensor and the by-pass path and is combined by said light combining means, or light of a single frequency emerging from the combining means is combined with light of a different frequency derived from said light generating means, before the light is fed to a heterodyning optical detector, in which the light passing through said fibre optic sensor will be phase modulated due to variations in the characteristics of the fibre optic sensor during operation of the interferometer and in which means is provided for preventing the generation of more than one time-divisionmultiplex signal by said heterodyning optical detector, or at least preventing the arrival of more than one such timedivision-multiplex signal at the input of a phase or frequency modulation receiver coupled to the optical detector.

2. An interferometer as claimed in claim 1, in which the light derived from the light generating means is arranged to alternate between two different frequencies (W1 and W2) for like p riods of time (t) and is routed through said two paths simultaneously, the length of the fibre optic sensor path being such that the light passing therethrough is delayed by a period (t) relative to the light passing through the by-pass reference path.

3. An interferometer as claimed in claim 2, in which the light derived from the light generating means alternates between the two

different frequencies (W1 and W2) for consecutive periods (t) without interruption whereby the light output from light combining means falling upon the optical detector produces an output comprising two time-division-multiplexed signals and which gating means is introduced between the output of the optical detector and the phase or frequency modulation receiver or demodulator to switch one of the time-division-multiplex signals out of the path to the demodulator.

4. An interferometer as claimed in claim 2, in which the light alternating between two different frequencies (W1 and W2) for like time periods (t) is interrupted by the operation of switching means to produce the absence of light for a period (t) following successive alterations in frequency from one frequency (W1) to the other frequency (W2) whereby the output from the optical detector comprises a single phase modulated signal which is fed to the phase or frequency modulation receiver of demodulator.

5. An interferometer as claimed in any preceding claim, in which the light of two different frequencies is produced by a bragg cell driven by a suitable modulating signal and in which switching means is provided to select in turn the light at the two different frequencies in order to produce alternate like periods (t) of light at the two frequencies.

6. An interferometer substantially as hereinbefore described with reference to Figs. 1 and 2 of the accompanying drawings.

7. An interferometer substantially as hereinbefore described with reference to Figs. 3 and 4 of the accompanying drawings.

8. A hydrophone comprising an interferometer as claimed in any preceding claim.

Printed in the United Kingdom for
Her Majesty's Stationery Office, Dd 8818935. 1985, 4235.
Published at The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained